# From parametric design to tangible interfaces: lowering the threshold for making.

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**Abstract**

Fablabs provide people with the possibility of making (almost) any object, by sharing digital fabrication tools and knowledge on making. However, to use these tools require experience in designing with 2D or 3D computer-aided design programs, that are mostly created with expert-users in mind. In the research project "Bespoke Design" we made personal self-management tools for and together with type 1 diabetics. One of the findings of Bespoke Design was that making personal designs without the support of a designer is not feasible for non-expert users, mainly due to difficulties of translating their idea into a digital model or drawing. Furthermore, we noticed that the needs of people with diabetes change over time. This demands for a design that evolves according to these changes. Parametric design tools can offer a solution since it enables (non-expert) users to make small changes to the design. However, these changes are limited to the confinements imposed by the designer. Therefore, parametric design falls short when the objective is really involving participants in designing from scratch. We state that adopting tangible interfaces that use more natural interactions can lower the threshold for non-expert users in Fablabs, bridging the gap towards personal fabrication.

**Keywords**

*Fablabs, non-expert users, parametric design, tangible interfaces*

## 1 Introduction

The promise of digital fabrication on how to make almost anything (Gershenfeld, 2005) is driven by advances in CNC (computer numerical control) technologies like 3D printing, laser cutting and milling machines. These tools have become cheaper, are widely adopted by fablabs, makerspaces and remove many of the barriers experienced with traditional manufacturing tools, thus providing an exciting opportunity for individuals without mechanical engineering or manufacturing backgrounds to make things. To make something, a user merely needs to access a computer and create (or download) a design in the correct format and and monitor the machine during the making process (Hurst & Kane, 2013). Over the years, the rapid growth of fablabs worldwide as well as numerous online communities (e.g. Instructables, Thingiverse, Ponoko, etc.) fuel the maker culture through helping the general public to share designs, inspiration and experiences and provide access to CNC driven technologies (Hurst & Kane, 2013).

Although the group of people using digital fabrication tools is growing considerably, many challenges still remain. One of the pressing barriers is the fact that the development of software design tools are not appropriated for this new audience of non-expert users. Many software design tools are in fact still designed with expert-users in mind, impeding someone who is just making the first steps into for instance creating 3D objects (Mellis, 2014). These tools have steep learning curves and do not take into account that learning to use the software to create digital models is not the goal but just a necessary means to make the physical object (Schmidt & Ratto 2013).

By providing a detailed description of the research project ‘Bespoke Design’ which deals with the participatory design of self-management tools for and with people with type 1 diabetes, we approach the problem of designing self-management tools as a participatory design process where everyone (designers and participants) is actively involved in the design and making process from idea to finished product. By describing the different choices that are made and the problems we encountered during this process, we highlight the benefits and shortcomings of using parametric design by non-expert users and designers to make adaptive self-management tools. Building further on these insights we propose that direct physical manipulation is even easier for non-expert users, who can have more control over the design process via tangible interfaces (Ishii & Ullmer, 1997).

## 2 Related work

Recently, maker culture has gained momentum in healthcare, where it encourages novel applications of technologies to healthcare problems and the exploration of intersections between traditionally separate domains. For example, modular prototyping processes allow the modification of open source designs of 3D printed prosthetics and assistive devices (Hofmann 2015). An important driver for making personalised care solutions is the idea that these objects often prove to work better than their off-the-shelf solutions counterparts (Hurst & Tobias, 2011) and that they can co-evolve with the changing health condition they were designed for. Or, as stated by Hurst and Kane (2013, p. 636): “the ability to rapidly prototype and customize technology can also help them make the decision to adopt or modify existing technology (as needs or preferences change).” A number of organizations or initiatives are very active in this domain. For instance, Instructables (http://www.instructables.com) features numerous assistive technology projects and DiYability (http://diyability.org) highlights novel assistive technology solutions developed by the DIY (Do It Yourself) community. Other interesting examples come from the field of prosthetics: Open Bionics (http://www.openbionics.org) and Enabling the future (http://enablingthefuture.org/) are both initiatives for creating low-cost, lightweight, underactuated robot hands and prosthetic devices; The Open Prosthetics Project (http://openprosthetics.org) is an open-source collaboration between users, designers, and funders to develop and share prosthetic innovations. Design for (every)one, a Flemish research and education project (http://designforeveryone.howest.be), aims to co-design personalised assistive technologies in multidisciplinary teams of students, patients and occupational therapists.

Makehealth from the Waag Society (https://waag.org/en/project/makehealth) supports healthcare professionals to explore digital fabrication labs and their makers to create new healthcare solutions. Their aim is to empower patients by organizing moments that multidisciplinary teams can work together on problems experienced by certain patients.

Although (personal fabrication) technologies and platforms are becoming more and more available and accessible, important barriers for creating personalised tools or objects by non-expert users still remain. The mere knowledge and use of these platforms is not sufficient to take the step towards the actual making. What is lacking, are insights in the technology and its possibilities through hands-on demonstrations, and more specifically, the way in which the technology can support people's personal needs (Hook et al, 2014; Kim & Yeh, 2015). Furthermore, a lack of practical skills among non-expert users on how to design for or use the specific technology, but also a lack of confidence can be identified as important thresholds in making personalised tools or technologies (Hook et al., 2014; Moraiti et al., 2015). Finally, Hudson et al. (2016) report that newcomers to 3D printing are very reliant on print centre operators but that these operators in fact do not fully understand the newcomers' needs.

# 3 Bespoke design a case study

'Bespoke Design' (OPAK, www.designopmaat.be) is a three year research project that focuses on the design and development of bespoke self-management tools for and together with persons with type 1 diabetes. The aim of this project was to make non-medical tools that assist the participants in making their diabetes easier to manage. The essence of diabetes type 1 is that the body targets insulin producing cells, meaning that carbohydrates cannot be broken down which leads to high blood glucose levels. People with this type of diabetes need to inject insulin in relation to carbohydrates intake, exercise, weather and other variables. Having a too low glucose level (hypoglycemia) induces dizziness, sweating and general uncomfort for the person with diabetes or even - when not treated by eating carbohydrates - trigger a comatose state. On the other hand, when having high blood glucose level (hyperglycemia) people with type 1 diabetes experience, increased thirst, frequent urination, headache and blurred vision. Since the person with diabetes is the one that is responsible to meticulously manage and maintain a good blood glucose level, he/she carries around tools to test and adjust their blood glucose level at all times. In this project, we designed together with people with diabetes, objects to make their life easier resulting in holders for an insulin pump, sugar dispensers and a dress that allows discretely injecting insulin in public. Since the aim of Bespoke Design was to involve users in exploring design problems, designing prototypes and the actual production of the final object, we used a co-design process in which we designed together with people instead of for them.

While designing for one person in a project over a timespan of three years, going from a personalised idea to a working prototype, required a lot of iterations. For example, using a 3D printer in this process enabled us to make fast prototypes of the insulin pump holders, but printing these took more time than the person with diabetes reserved. At the start of the project, the idea was to involve the persons with diabetes in every step of the design and making process, but doing so every iteration ment planning a new evaluation or design session. This means that the involvement for the diabatic was non-proportional to the proposed solution. Thus what happens is that the designers skipped involving the diabetic in every step and started working without them, pulling the project more towards a traditional make process. This shifted the ownership of the object more towards the designer, disconnecting the diabetic from the design and fabrication process.

Since the process of making an object takes quite some time, we experienced that the needs of the people with diabetes can shift (new glucose meter, different shape of dextrose, etc.) in the meantime (between the start of the design process and the actual production of the object). This clearly illustrates that one personalised design without a way of altering it, makes this process (of co-designing personalised self-management tools) not sustainable. At the start of Bespoke Design, we did not anticipated these potential changes of needs. Therefore we designed the object using standard CAD technology (Autodesk Inventor, Rhino). Adjusting the model requires expert knowledge of these CAD environments, which was not the case with the diabetics involved in the project. Hence, to increase the longevity of the designed object, we figured that if the user can alter the design to his/her changing needs, the role of the designer becomes obsolete. One way to alter the design without knowledge of CAD software is to make a parametric model.

## 4 What is parametric design?

Parametric design refers to the relations between sizes, angles and shapes of a certain part of an object to another part of the object (Roller 1991). When adjusting one of these parameters the rest will follow according to a predefined algorithm defined by the designer. An example of parametric design is Sketch a chair (http://www.sketchchair.cc) where users can draw a side profile of a chair and the software creates a 3D model of it. The user can adjust parameters like width and spacing by using sliders. Cookie Caster (http://www.cookiecaster.com) does the same, by drawing the shape of a cookie cutter in the topview, it will generate a full 3D-model ready for 3D-printing.

### 4.1 Parametric design of bespoke design

One of the prototypes we created in Bespoke Design was a sugar dispenser that provided the person with diabetes with fast access to sugar when having a hypoglycemia. We started designing a sugar dispenser for round shaped dextrose (Figure 1), but during the design process the user shifted to rectangular (Figure 2) dextrose. Although many of the mechanics of

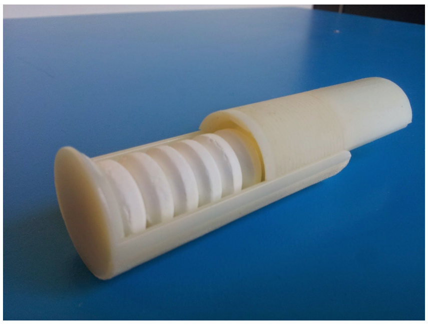

Figure 1: Round dextrose sugar dispenser

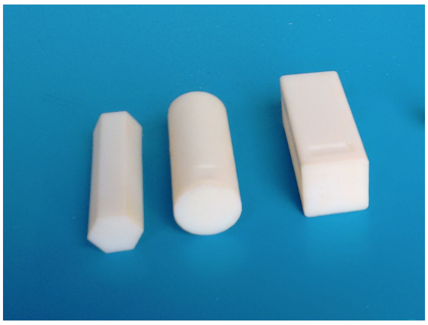

Figure 2: Different shape dextrose sugar dispenser

the dispenser were the same, the object needed to be fully redesigned. Because of the use of standard CAD software the person with diabetes was not able to adjust the model herself. Therefore, we redesigned it to a parametric model, allowing the user to interact with the model by changing the width, height, size and shape of the dextrose through sliders. The first parametric 3D model is made using Grasshopper for Rhino, a node based environment that allows the designer to drag and drop nodes with individual functions (e.g. circle, extrude, etc.) and create relationships between them. In order to let diabetics alter the design they need to buy and install Rhino. Because the software is proprietary it is expensive and has no easy frontend it is not the best solution for them. So we looked for a open source alternative and designed a model for Openscad (http://www.openscad.org). This is an open source syntax based 3D modeling software that allows to define the relations in code. This made it possible to upload the 3D model to the online platform Thingiverse (http://www.thingiverse.com) where the participants of Bespoke Design (i.e. people with diabetes) could use the "customizer" (http://www.thingiverse.com/thing:699562) as an user interface for adjusting the model. In this way the user could to modify the model (of the sugar dispenser in this case) without installing specific software on their computer and download the necessary files to 3D-print the object.

## 4.2 Limitations of parametric design

As parametric design is a procedural driven process, the designers adds complexity to the object with each defined parameter. Therefore with each node added, the complexity of relationship between nodes grows exponentially. A lot of effort in designing a model resides in defining the relationships between parameters (Naglaa, 2015). If the designer uses a lot of parameters not all relationships are defined in such a way that the resulting model is producible. By doing this the designer restricts the non-expert user to a limited number of possible outcomes.

Yumer et al. (2015) conclude that having a lot of parameters does not mean that users can make the desired model, since adjusting the parameters using sliders does not show the underlying complexity of the relationships. To overcome this, they propose a visual based system showing 3D models with different parametric configurations (Figure 3) and an interactive 3D model that can be manoeuvred in between a limited number of possible visual shapes while it automatically changes it shape. This visual process provides the non-expert user with a better understanding of the possibilities.

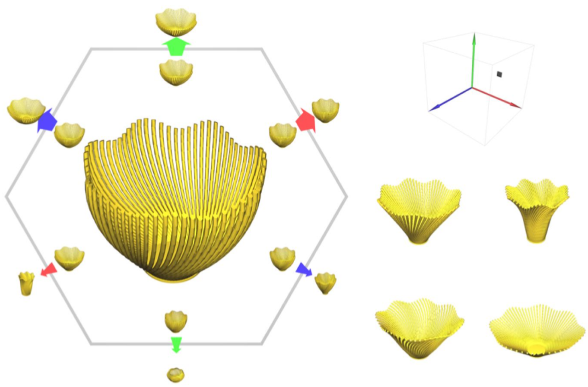

Figure 3: Procedural Modeling Using Autoencoder Networks

In Bespoke Design, we noticed that through parametric design we could enable non expert users to adjust the sugar dispenser, but the actual involvement in the making process that took part in the Fablab was reduced to adjusting parameters. We believe that the involvement of users in the digital fabrication process could be increased by using interfaces that have a lower threshold for non-expert users. After all, 3D modelling has a steep learning curve for non-expert users because the 3D interactions need to be done on a 2D screen with mouse and keyboard creating a gap between the physical and digital world (Jacob et al. 1994).

## 5 Tangible interfaces for designing objects

When constructing an object using non-digital tools the designer can interact with the physical properties of the material, an advantage we lose when using digital interfaces. In the field of computer sciences, tangible user interfaces (TUI) connect physical objects to digital interfaces. Ishii and Ulmer state that when using tangible interfaces the digital 2D and 3D manipulation improve(Ullmer & Ishii, 2000) (Voelker, 2015).

In this section we provide a short overview of projects that could lower the threshold for making 3D-objects. We distinguish between two categories of TUI: one are tangible tools that help the user in making a 3D model, while the second one are construction kits to create a physical model of the object which is then automatically translated into a digital 3D model.

Sheng et al (2006) developed a tangible tool for sculpting 3D models; using a tracking system it measures deformations in a sponge like object and applies it to a digital model. ShapeTape (Grossman, 2003) measures deflection with a specialized high degree-of-freedom curve input device that enables users to manipulate digital curves in 2D and 3D. Enabling users to have more direct control over digital shapes in virtual environments.

When connecting measurement tools to a digital interface it is possible to create 3D models. HandSCAPE (Lee, 2000) is a digital tape measurement device that transfers the measured data to a digital interface and constructs a 3D model out of it. Weichel (2015) made callipers (SPATA) that used bi-directional communication, so that it not only sends data to a digital interface but also can receive data and physically change the callipers opening to any size. Giving the user tangible feedback on the actual size of the digital model.

MixFab (Weichel, 2014) uses a mixed reality device that allows users to use physical objects under a see through display that overlays the digital environment. All the objects that are brought under the screen are 3D scanned and made into a digital model. Allowing the user to make gesture based transformation like unions, subtraction, scaling of the digital objects.

Reform (Weichel, 2015) uses bi-directional fabrication, using additive and subtractive techniques in one machine. It uses a 3D printer, cnc milling and 3D scanner with a see through overlaid display. Using clay the user can model a design by hand, put the model in the machine. The machines scans the object and saves the current state. The user can let the machine print on or mill the model and undo actions.

Tools like these try to digitize objects from the physical world to 3D digital models. They use innovative interaction techniques that enable non-expert users to sculpt or model 3D objects. When combined with digital fabrication techniques these tools could be valuable assets for designing and manufacturing of objects.

### 5.1 Construction kits

In construction kit toys like Lego, Knex and Duplo, the effort of building 3D-objects is not the same as building a digital 3D model. Gorbet (1998) presented triangles, one of the first construction kits with a bi-directional feedback system. The physical triangle uses an embedded microcontroller to communicate with other triangles or a desktop PC. Depending on the orientation of the triangles the information that is being displayed changes. Since then, a variety of construction kits being developed (Kitamura, Yoshifumi et a, 2000) (Sharlin, 2001) (Miller, 2012) most using a Lego-like construction system. One disadvantage of this system is that it is being constrained by the physical shape of the block, limiting angles and organic shapes.

Jacobs (2014) presented a physical interface that consists of interchangeable, hot pluggable parts.(Figure 4) This interface measures the angle by integrating a sensor in each interchangeable part. When doing animation of 3D characters a lot of involved organic motions have to be animated. Using a mouse and keyboard makes this a difficult and time consuming task. User testing shows that first time users are faster with the tangible interface in comparison to mouse and keyboard.

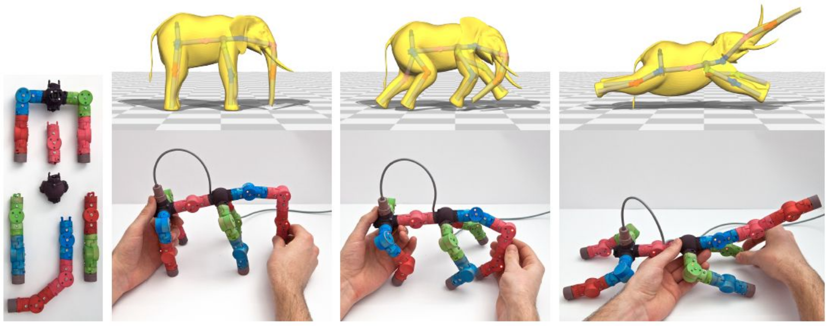

Figure 4: Procedural Modeling Using Autoencoder Networks

By using tangible interfaces to manipulate physical models, users immediately get a sense of proportions and dimensions . It allows users to do tasks faster compared to mouse and keyboard interfaces (Jacobson, 2014). The use of tangible interfaces in computer sciences has a long history, originally designed for manipulating software. However, the use of this technique can easily adopted for digital fabrication processes .

## 6 Discussion

In the process of Bespoke Design, the designer translated the idea into 3D CAD drawings and adds his own expertise to the project. When non-expert user start designing with traditional CAD design tools they face a steep learning curve, when designing objects and leaving out the expertise of a designer the results can be inadequate. If we are going to design tangible interfaces we need to incorporate the knowledge of the designer. In this case the designer needs to decompose the 3D model to add a layer of abstraction to an object.

When empowering non-expert users to make objects through tangible interfaces, the question remains if they can translate an idea into a working prototype. The current set of 3D printers, cnc-milling machines and laser cutters still have a need for expert knowledge. Fablabs can play a key role in the development of new digital fabrication interfaces. Knowing best how digital fabrication processes are used can be beneficial to translate the needs of non-experts users into (tangible) interfaces that could enable them to use digital fabrication tools. When designing new interfaces there are always questions about how much control over the proces non-experts users need to make 3D-models.

## 7 Conclusion

We learned from Bespoke Design that a long-term participatory design process can be a challenging process. The designer has to find the right balance between allowing the freedom to create an useable object and keeping the diabetic involved in the design process from idea to functional object. In the process we did not account for the changing needs of the diabetic and we were confronted with the limits of traditional CAD software. When non-expert users want to make an object they are not interested in learning CAD modelling tools with steep learning curves. They try to go from idea to object in the most simple way. In the project bespoke design we made designs with traditional CAD software, the diabetics were not able to alter the design. By doing this the diabetic relies on the designer to make changes over time. Throughout the design process we changed to an online parametric design tools, where diabetics could modify the design using sliders, so that the sugardispenser could fit their actual needs. By doing this online non-expert users can modify design using a web browser without the need for installing expensive proprietary software. We noticed that using this parametric design tools users could modify designs but they are limited by the parameters that are defined by the designer. If the objective is to let non-expert users design their own objects, we need to find a way to overcome software with steep learning curves.

Tangible interfaces promise more natural interactions and can lose the abstraction layer that is a mouse and keyboard. A lot of tangible interfaces are developed within computer sciences that could benefit non-expert users and digital fabrication. The Spata, Remix and Reform tools by Christian Weichel show how tools could alter the design and fabrication process for non-expert users by enabling a more intuitive interface. With the construction kits non-experts users can make simple digital 3D-models with building blocks that snap together and have a real sense of proportions en dimensions of the actual object without fabricating it. More research is needed to refine physical interfaces that enable non-expert users to use digital fabrication tools. By doing this we can enable the full potential of digital fabrication not only to a small group of expert users, but to the bigger group of non-expert users.

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